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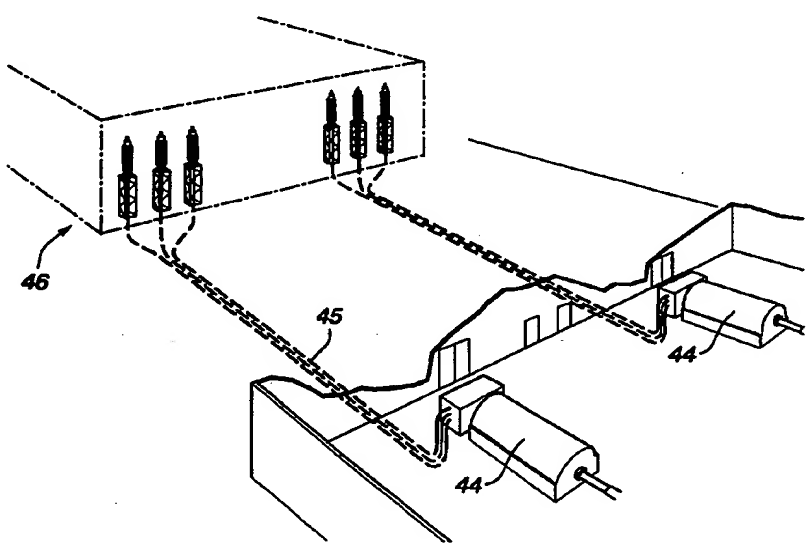

(57) Abstract

A switch gear station comprises at least one switch gear (46) and at least one rotating electric machine (44) for high voltage. The machine comprises at least one winding including at least one electric conductor. The conductor has an insulation system comprising an insulation formed by a solid insulation material and, inwardly of the insulation, an inner layer having an electric conductivity which is lower than the conductivity of the electric conductor but sufficient to cause the inner layer to operate for equalisation as concerns potential and, accordingly, equalisation as concerns the electric field exteriorly of the inner layer. This design of the conductor enables direct connection of the winding of the rotating electric machine to a voltage power network.

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Switch gear station

FIELD OF THE INVENTION AND PRIOR ART

This invention is related to a switch gear station comprising at least one switch gear and at least one rotating electric machine comprising at least one winding including at least one electric conductor.

Such electric machines comprise synchronous machines which are mainly used as generators for connection to distribution and transmission networks, commonly referred to below as power networks. The synchronous machines are also used as motors and for phase compensation and voltage control, in that case as mechanically idling machines. The technical field also comprises double-fed machines, asynchronous converter cascades, external pole machines, synchronous flux machines and asynchronous machines.

The winding may in some embodiments be air-wound but as a rule the magnetic circuit comprises a magnetic core of laminated, normal or oriented, sheet or other, for example amorphous or powder-based, material, or any other action for the purpose of allowing an alternating flux. The circuit often comprises some kind of cooling system etc. The winding may be disposed in the stator or the rotor of the machine, or in both.

In order to be able to explain and describe the invention, the prior art will be discussed hereinafter.

The rotating electric machine will be exemplified based upon a synchronous machine. The first part of the description substan-

tially relates to the magnetic circuit of such a machine and how it is composed according to classic technique. Since the magnetic circuit referred to in most cases is disposed in the stator, the magnetic circuit below will normally be described as a stator with a laminated core, the winding of which will be referred to as a stator winding, and the slots in the laminated core for the winding will be referred to as stator slots or simply slots.

Most synchronous machines have a field winding in the rotor, where the main flux is generated by direct current, and an ac winding in the stator. The synchronous machines are normally of three-phase design. Sometimes, the synchronous machines are designed with salient poles. The latter have an ac winding in the rotor.

The stator body for large synchronous machines are often made of sheet steel with a welded construction. The laminated core is normally made from varnished 0.35 or 0.5 mm electric sheet. For larger machines, the sheet is punched into segments which are attached to the stator body by means of wedges/dovetails. The laminated core is retained by pressure fingers and pressure plates.

For cooling of the windings of the synchronous machine, three different cooling systems are available.

In case of air cooling, both the stator winding and the rotor winding are cooled by cooling air flowing through. The cooling air channels are to be found both in the stator laminations and in the rotor. For radial ventilation and cooling by means of air, the sheet iron core at least for medium-sized and large machines is divided into stacks with radial and axial ventilation ducts disposed in the core. The cooling air may consist of ambient air but at high power a closed cooling system with heat exchangers is substantially used. Hydrogen cooling is used in turbogenerators

and in large synchronous compensators. The cooling method functions in the same way as in air cooling with heat exchangers, but instead of air as coolant there is used hydrogen gas. The hydrogen gas has better cooling capacity than air, but difficulties arise at seals and in monitoring leakage. For turbogenerators in the higher power range it is known to apply water cooling of both the stator winding and the rotor winding. The cooling channels are in the form of tubes which are placed inside conductors in the stator winding. One problem with large machines is that the cooling tends to become non-uniform and that, therefore, temperature differences arise across the machine.

The stator winding is disposed in slots in the sheet iron core, the slots normally having a cross section as that of a rectangle or a trapezoid. Each winding phase comprises a number of series-connected coil groups and each coil group comprises a number of series-connected coils. The different parts of the coil are designated coil side for that part which is placed in the stator and coil end for that part which is disposed outside the stator. A coil comprises one or more conductors brought together in height and/or width. Between each conductor there is a thin insulation, for example epoxy/glass fibre.

The coil is insulated against the slot with a coil insulation, that is, an insulation intended to withstand the rated voltage of the machine to ground. As insulating material, various plastic, varnish and glass fibre materials may be used. Usually, so-called mica tape is used, which is a mixture of mica and hard plastic, especially produced to provide resistance to partial discharges, which can rapidly break down the insulation. The insulation is applied to the coil by winding the mica tape around the coil in several layers. The insulation is impregnated, and then the coil side is painted with a coal-based paint to improve the contact

with the surrounding stator which is connected to ground potential.

The conductor area of the windings is determined by the current intensity in question and by the cooling method used. The conductor and the coil are usually formed with a rectangular shape to maximize the amount of conductor material in the slot. A typical coil is formed of so-called Roebel bars, in which certain of the bars may be made hollow for a coolant. A Roebel bar comprises a plurality of rectangular, parallel-connected copper conductors, which are transposed 360 degrees along the slot. Ringland bars with transpositions of 540 degrees and other transpositions also occur. The transposition is made to avoid the occurrence of circulating currents which are generated in a cross section of the conductor material, as viewed from the magnetic field.

For mechanical and electrical reasons, a machine cannot be made in just any size. The machine power is determined substantially by three factors:
- The conductor area of the windings. At normal operating temperature, copper, for example, has a maximum value of 3-3.5 A/mm^2.
- The maximum flux density (magnetic flux) in the stator and rotor material.
- The maximum electric field strength in the insulating material, the so-called dielectric strength.

Polyphase ac windings are designed either as single-layer or two-layer windings. In the case of single-layer windings, there is only one coil side per slot, and in the case of two-layer windings there are two coil sides per slot. Two-layer windings are usually designed as diamond windings, whereas the single-layer windings which are relevant in this connection may be designed as a diamond winding or as a concentric winding. In the case of a

diamond winding, only one coil span (or possibly two coil spans) occurs, whereas flat windings are designed as concentric windings, that is, with a greatly varying coil width. By coil width is meant the distance in circular measure between two coil sides belonging to the same coil, either in relation to the relevant pole pitch or in the number of intermediate slot pitches. Usually, different variants of chording are used, for example fractional pitch, to give the winding the desired properties. The type of winding substantially describes how the coils in the slots, that is, the coil sides, are connected together outside the stator, that is, at the coil ends.

Outside the stacked sheets of the stator, the coil is not provided with a painted semiconducting ground-potential layer. The coil end is normally provided with an E-field control in the form of so-called corona protection varnish intended to convert a radial field into an axial field, which means that the insulation on the coil ends occurs at a high potential relative to ground. This sometimes gives rise to corona in the coil-end region, which may be destructive. The so-called field-controlling points at the coil ends entail problems for a rotating electric machine.

Normally, all large machines are designed with a two-layer winding and equally large coils. Each coil is placed with one side in one of the layers and the other side in the other layer. This means that all the coils cross each other in the coil end. If more than two layers are used, these crossings render the winding work difficult and deteriorate the coil end.

It is generally known that the connection of a synchronous machine/generator to a power network must be made via a Δ/Y-connected so-called step-up transformer, since the voltage of the power network normally lies at a higher level than the voltage of the rotating electric machine. Together with the synchronous machine, this transformer thus constitutes integrated parts

of a plant. The transformer constitutes an extra cost and also entails the disadvantage that the total efficiency of the system is lowered. If it were possible to manufacture machines for considerably higher voltages, the step-up transformer could thus be omitted.

During the last few decades, there have been increasing requirements for rotating electric machines for higher voltages than what has previously been possible to design. The maximum voltage level which, according to the state of the art, has been possible to achieve for synchronous machines with a good yield in the coil production is around 25-30 kV.

Certain attempts to a new approach as regards the design of synchronous machines are described, inter alia, in an article entitled "Water-and-oil-cooled Turbogenerator TVM-300" in J. Elektrotechnika, No. 1, 1970, pp. 6-8, in US 4,429,244 "Stator of Generator" and in Russian patent document CCCP Patent 955369.

The water- and oil-cooled synchronous machine described in J. Elektrotechnika is intended for voltages up to 20 kV. The article describes a new insulation system consisting of oil/paper insulation, which makes it possible to immerse the stator completely in oil. The oil can then be used as a coolant while at the same time using it as insulation. To prevent oil in the stator from leaking out towards the rotor, a dielectric oil-separating ring is provided at the internal surface of the core. The stator winding is made from conductors with an oval hollow shape provided with oil and paper insulation. The coil sides with their insulation are secured to the slots made with rectangular cross section by means of wedges. As coolant oil is used both in the hollow conductors and in holes in the stator walls. Such cooling systems, however, entail a large number of connections of both oil and electricity at the coil ends. The thick insulation also entails an increased

radius of curvature of the conductors, which in turn results in an increased size of the winding overhang.

The above-mentioned US patent relates to the stator part of a synchronous machine which comprises a magnetic core of laminated sheet with trapezoidal slots for the stator winding. The slots are tapered since the need of insulation of the stator winding is smaller towards the interior of the rotor where that part of the winding which is located nearest the neutral point is disposed. In addition, the stator part comprises a dielectric oil-separating cylinder nearest the inner surface of the core. This part may increase the magnetization requirement relative to a machine without this ring. The stator winding is made of oil-immersed cables with the same diameter for each coil layer. The layers are separated from each other by means of spacers in the slots and secured by wedges. What is special for the winding is that it comprises two so-called half-windings connected in series. One of the two half-windings is disposed, centred, inside an insulating sleeve. The conductors of the stator winding are cooled by surrounding oil. Disadvantages with such a large quantity of oil in the system are the risk of leakage and the considerable amount of cleaning work which may result from a fault condition. Those parts of the insulating sleeve which are located outside the slots have a cylindrical part and a conical termination reinforced with current-carrying layers, the duty of which is to control the electric field strength in the region where the cable enters the end winding.

From CCCP 955369 it is clear, in another attempt to raise the rated voltage of the synchronous machine, that the oil-cooled stator winding comprises a conventional high-voltage cable with the same dimension for all the layers. The cable is placed in stator slots formed as circular, radially disposed openings corresponding to the cross-section area of the cable and the necessary space for fixing and for coolant. The different radially dis-

posed layers of the winding are surrounded by and fixed in insulating tubes. Insulating spacers fix the tubes in the stator slot. Because of the oil cooling, an internal dielectric ring is also needed here for sealing the oil coolant against the internal air gap. The design also exhibits a very narrow radial waist between the different stator slots, which means a large slot leakage flux which significantly influences the magnetization requirement of the machine.

A report from Electric Power Research Institute, EPRI, EL-3391, from 1984 describes a review of machine concepts for achieving a higher voltage of a rotating electric machine for the purpose of being able to connect a machine to a power network without an intermediate transformer. Such a solution is judged by the investigation to provide good efficiency gains and great economic advantages. The main reason that it was considered possible in 1984 to start developing generators for direct connection to power networks was that at that time a superconducting rotor had been produced. The large magnetization capacity of the superconducting field makes it possible to use an air gap winding with a sufficient thickness to withstand the electrical stresses. By combining the most promising concept, according to the project, of designing a magnetic circuit with a winding, a so-called monolith cylinder armature, a concept where the winding comprises two cylinders of conductors concentrically enclosed in three cylindrical insulating casings and the whole structure is fixed to an iron core without teeth, it was judged that a rotating electric machine for high voltage could be directly connected to a power network. The solution meant that the main insulation had to be made sufficiently thick to cope with network-to-network and network-to-ground potentials. Obvious disadvantages with the proposed solution are that, in addition to requiring a superconducting rotor, it requires a very thick insulation which increases the size of the machine. The coil ends must be insulated and cooled with oil or freons to control

the large electric fields in the ends. The whole machine must be hermetically enclosed to prevent the liquid dielectric from absorbing moisture from the atmosphere.

As appears from the above description, switch gear stations of today are susceptible of being improved. This is due to the generator embodiment itself and to the fact that according to the prior art "step-up"-transformers are required.

It is pointed out that the term switch gear station here relates to a station, which is intended for collecting and/or distributing electric power and comprises equipment required for such activity, including a.o. equipment for switching and supervising.

SUMMARY OF THE INVENTION

The object of the present invention is primarily to provide a switch gear station, in which at least some of the disadvantages discussed hereinabove and impairing the prior art have been eliminated.

The primary object is obtained by means of a station of the kind defined in the enclosed claims, and then particularly in claim 1.

In a broad sense it is established that the design according to the invention reduces, since it creates a possibility to substantially enclose the electric field occurring due to said electric conductor within the insulation system, the occurring losses such that the machine, accordingly, may operate with a higher efficiency. The reduction of losses involves, in its turn, a lower temperature in the device, which reduces the cooling requirement and makes it possible to design possibly occurring cooling devices as more simple than should the invention be absent.

The conductor/insulation system according to the invention may be realised as a flexible cable, which means substantial advantages with respect to production and mounting as compared to the prefabricated, rigid windings which have been conventional up to now. The insulation system used according to the invention results in absence of gaseous and liquid insulation materials.

The rotating electric machine of the invention thus makes it possible to operate the machine with such a high voltage that the step-up transformer mentioned above can be omitted. That is, the machine can be operated with a considerably higher voltage than machines according to the state of the art to be able to perform direct connection to power networks. This means considerably lower investment costs for systems with a rotating electric machine and the total efficiency of the system can be increased. The invention eliminates the need for particular field control measures at certain areas of the winding, such field control measures having been necessary according to the prior art. A further advantage is that the invention makes it more simple to obtain under- and overmagnetization for the purpose of reducing reactive effects as a result of voltage and current being out of phase with each other. Thus, the switch gear station in its entirety becomes more efficient by reduced losses. In addition, the station in its entirety is simplified so that it becomes not only more non-expensive but also less space consuming.

The design of the winding so that it comprises, along at least a part of its length, an insulation formed by a solid insulating material, inwardly of this insulation an inner layer and outwardly of the insulation an outer layer with these layers made of a semi conducting material makes it possible to enclose the electric field in the entire device within the winding. The term "solid insulating material" used herein means that the winding is to lack liquid or gaseous insulation, for instance in the form of oil. In-

stead the insulation is intended to be formed by a polymeric material. Also the inner and outer layers are formed by a polymeric material, though a semiconducting such.

The inner layer and the solid insulation are rigidly connected to each other over substantially the entire interface. Also the outer layer and the solid insulation are rigidly connected to each other over substantially the entire interface therebetween. The inner layer operates equalising with respect to potential and, accordingly, equalising with respect to the electrical field outwardly of the inner layer as a consequence of the semiconducting properties thereof. The outer layer is also intended to be made of a semiconducting material and it has at least an electrical conductivity being higher than that of the insulation so as to cause the outer layer, by connection to earth or otherwise a relatively low potential, to function equalising with regard to potential and to substantially enclose the electrical field resulting due to said electrical conductor inwardly of the outer layer. On the other hand, the outer layer should have a resistivity which is sufficient to minimize electrical losses in said outer layer.

The rigid interconnection between the insulating material and the inner and outer semiconducting layers should be uniform over substantially the entire interface such that no cavities, pores or similar occur. With the high voltage levels contemplated according to the invention, the electrical and thermal loads which may arise will impose extreme demands on the insulation material. It is known that so-called partial discharges, PD, generally constitute a serious problem for the insulating material in high-voltage installations. If cavities, pores or the like arise at an insulating layer, internal corona discharges may arise at high electric voltages, whereby the insulating material is gradually degraded and the result could be electric breakdown through the insulation. This may lead to serious breakdown of the electromagnetic device. Thus, the insulation should be homogenous.

The inner layer inwardly of the insulation should have an electrical conductivity which is lower than that of the electrical conductor but sufficient for the inner layer to function equalising with regard to potential and, accordingly, equalising with respect to the electrical field externally of the inner layer. This in combination with the rigid interconnection of the inner layer and the electrical insulation over substantially the entire interface, i.e. the absence of cavities etc, means a substantially uniform electrical field externally of the inner layer and a minimum of risk for PD.

It is preferred that the inner layer and the solid electrical insulation are formed by materials having substantially equal thermal coefficients of expansion. The same is preferred as far as the outer layer and the solid insulation is concerned. This means that the inner and outer layers and the solid electrical insulation will form an insulation system which on temperature changes expands and contracts uniformly as a monolithic part without those temperature changes giving rise to any destruction or disintegration in the interfaces. Thus, intimacy in the contact surface between the inner and outer layers and the solid insulation is ensured and conditions are created to maintain this intimacy during prolonged operation periods.

Furthermore, it is pointed out that it is essential that the materials in the inner and outer layers and in the solid insulation have a high elasticity so that the materials are capable of withstanding the strains occurring when the cable is bent and when the cable during operation is subjected to thermal strains. An efficient adherence between the solid insulation and the inner and outer layers and a high elasticity of these layers and the solid insulation respectively is particularly important in case the materials in the layers and the solid insulation would not have substantially equal coefficients of thermal expansion. Besides, it is

preferable that the materials in the inner and outer layers and in the solid insulation have substantially equal elasticity (E modulus), which will counteract occurrence of shear tensions in the border area between the layers and the solid insulation. It is preferred that the materials in the inner and outer layers and in the solid insulation have E modulus which is less than 500 MPA, preferably less than 200 MPA. In order to be able to form windings by means of the cable, it is essential that the flexibility thereof is high. It is preferred that the cable should be capable of be subjected to bending, without negative influence on the function, with a radius of bending which is 20 times the cable diameter or less, suitably 15 times the cable diameter or less. It is preferred that the cable should be capable of being bent to a radius of bending in the amount of 4 à 5 times the cable diameter or even less without adequate function being jeopardised.

The electrical load on the insulation system decreases as a consequence of the fact that the inner and the outer layers of semiconducting material around the insulation will tend to form substantially equipotential surfaces and in this way the electrical field in the insulation properly will be distributed relatively uniformly over the thickness of the insulation.

It is known, per se, in connection with transmission cables for high-voltage and for transmission of electric energy, to design conductors with an insulation of a solid insulation material with inner and outer layers of semiconducting material. In transmission of electric energy, it has since long been realised that the insulation should be free from defects. However, in high voltage cables for transmission, the electric potential does not change along the length of the cable but the potential is basically at the same level. However, also in high voltage cables for transmission purposes, instantaneous potential differences may occur due to transient occurrences, such as lightning. According to the

present invention a flexible cable according to the enclosed claims is used as a winding in the electromagnetic device.

An additional improvement may be achieved by constructing the electric conductor in the winding from smaller, so-called strands, at least some of which are insulated from each other. By making these strands to have a relatively small cross section, preferably approximately circular, the magnetic field across the strands will exhibit a constant geometry in relation to the field and the occurrence of eddy currents are minimized.

According to the invention, the winding/windings is/are thus preferably made in the form of a cable comprising at least one conductor and the previously described insulation system, the inner layer of which extends about the strands of the conductor. Outside of this inner semiconducting layer is the main insulation of the cable in the form of a solid insulation material.

The outer semiconducting layer shall according to the invention exhibit such electrical properties that a potential equalisation along the conductor is ensured. The outer layer may, however, not exhibit such conductivity properties that a current will flow along the surface, which could cause losses which in turn may create an unwanted thermal load. For the inner and outer layers the resistance statements (at 20°C) defined in the enclosed claims 5 and 6 are valid. With respect to the inner semiconducting layer, it must have a sufficient electrical conductivity to ensure potential equalisation for the electrical field but at the same time this layer must have such a resistivity that the enclosing of the electric field is ensured.

It is important that the inner layer equalizes irregularities in the surface of the conductor and forms an equipotential surface with a high surface finish at the interface with the solid insulation. The inner layer may be formed with a varying thickness but to

ensure an even surface with respect to the conductor and the solid insulation, the thickness is suitably between 0.5 and 1 mm.

Such a flexible winding cable which is used according to the invention in the rotating machine thereof is an improvement of a XLPE (cross-linked poly ethylene) cable or a cable with EP (ethylene-propylene) rubber insulation.. The improvement comprises, inter alia, a new design both as regards the strands of the conductors and in that the cable, at least in some embodiments, has no outer casing for mechanical protection of the cable. However, it is possible according to the invention to arrange a conducting metal shield and an outer mantle externally of the outer semiconducting layer. The metal shield will then have the character of an outer mechanical and electrical protection, for instance to lightning. It is preferred that the inner semiconducting layer will lie on the potential of the electrical conductor. For this purpose at least one of the strands of the electrical conductor will be uninsulated and arranged so that a good electrical contact is obtained to the inner semiconducting layer. Alternatively, different strands may be alternatingly brought into electrical contact with the inner semiconducting layer. Decisive advantage with the cable shaped winding according to the invention is that the electrical field is enclosed in the winding so that there will be no electrical field externally of the outer semiconducting layer. The electrical field obtained only occurs in the solid main insulation.

A substantially reduced thermal load on the stator is obtained. Temporary overloads of the machine will, thus, be less critical and it will be possible to drive the machine at overload for a longer period of time without running the risk of damage arising. This means considerable advantages for owners of power generating plants who are forced today, in case of operational disturbances, to rapidly switch to other equipment in order to ensure the delivery requirements laid down by law.

With a rotating electric machine according to the invention, the maintenance costs can be significantly reduced because transformers and circuit breakers do not have to be included in the system for connecting the machine to the power network.

Above it has already been described that the outer semiconducting layer of the winding cable is intended to be connected to ground potential. The purpose is that the layer should be kept substantially on ground potential along the entire length of the winding cable. It is possible to divide the outer semiconducting layer by cutting the same into a number of parts distributed along the length of the winding cable, each individual layer part being connectable directly to ground potential. In this way a better uniformity along the length of the winding cable is achieved.

Above it has been mentioned that the solid insulation and the inner and outer layers may be achieved by, for instance, extrusion. Other techniques are, however, also well possible, for instance formation of these inner and outer layers and the insulation respectively by means of spraying of the material in question onto the conductor/winding.

It is preferred that the winding cable is designed with a circular cross section. However, also other cross sections may be used in cases where it is desired to achieve a better packing density.

To build up a voltage in the rotating electric machine, the winding cable is disposed in several consecutive turns in slots in the magnetic core. The winding can be designed as a multi-layer concentric cable winding to reduce the number of coil-end crossings. The cable may be made with tapered insulation to utilize the magnetic core in a better way, in which case the shape of the slots may be adapted to the tapered insulation of

the winding.

A significant advantage with a rotating electric machine according to the invention is that the E field is near zero in the coil-end region outside the outer semiconductor and that with the outer casing at ground potential, the electric field need not be controlled. This means that no field concentrations can be obtained, neither within sheets, in coil-end regions or in the transition therebetween.

To sum up, thus, an electromagnetic device in the form of a rotating electric machine according to the invention means a considerable number of important advantages in relation to corresponding prior art machines. First of all, it can be connected directly to a power network at all types of high voltage. Another important advantage is that ground potential has been consistently conducted along at least a part of and preferably along the whole winding, which means that the coil-end region can be made compact and that bracing means at the coil-end region can be applied at practically ground potential.Oil-based insulation and cooling systems disappear also in rotating electric machines as already has been pointed out above. This means that no sealing problems may arise and that the dielectric ring previously mentioned is not needed. One advantage is also that all forced cooling can be made at ground potential.

BRIEF DESCRIPTION OF THE DRAWINGS

With reference to the enclosed drawings, a more specific description of embodiment examples of the invention will follow hereinafter.

In the drawings:

Fig 1 is a partly cut view showing the parts included in the current modified standard cable;

Fig 2 is an axial end view of a sector/pole pitch of a magnetic circuit according to the invention;

Fig 3 is a diagrammatical view illustrating prior art, i.e. a step-up-transformer coupled between a generator and an associated switch gear;

Fig 4 is a view illustrating a device according to the invention with the step-up-transformer eliminated;

Fig 5 is a perspective view illustrating a conventional generator plant;

Fig 6 is a similar view illustrating a simplification achieved as a consequence of use of the invention;

Fig 7 is a one-line diagram with respect to Static Var Compensation (SVC) and a switch gear according to prior art;

Fig 8 is a one-line diagram with respect to an embodiment according to the invention as a contrast to the conventional embodiment in fig 7;

Fig 9 is a one-line diagram regarding a switch gear station according to the prior art provided with a static converter in "back-to-back" design with a DC-link; and

Fig 10 is a one-line diagram illustrating, in contrast to the prior embodiment according to fig 9, how a switch gear station according to the invention having a rotating converter becomes much more simple and

requires a less amount of space as compared to the station according to fig 9 having a static converter.

DESCRIPTION OF PREFERRED EMBODIMENTS

An important condition for being able to manufacture a magnetic circuit in accordance with the invention, is to use for the winding a conductor cable with a solid electrical insulation with an inner semiconducting layer or casing between the insulation and one or more electrical conductors located inwardly thereof and with an outer semiconducting layer or casing located outwardly of the insulation. Such cables are available as standard cables for other power engineering fields of use, namely power transmission. To be able to describe an embodiment, initially a short description of a standard cable will be made. The inner current-carrying conductor comprises a number of strands. Around the strands there is a semiconducting inner layer. Around this semiconducting inner layer, there is an insulating layer of solid insulation. The solid insulation is formed by a polymeric material with low electrical losses and a high breakthrough strength. As concrete examples polyethylene (PE) and then particularly cross-linked polyethylene (XLPE) and ethylene-propylene (EP) may be mentioned. Around the outer semiconducting layer a metal shield and an outer insulation casing may be provided. The semiconducting layers consist of a polymeric material, for example ethylene-copolymer, with an electrically conducting constituent, e. g. conductive soot or carbon black. Such a cable will be referred to hereunder as a power cable.

A preferred embodiment of a cable intended for a winding in a rotating electrical machine appears from Fig 1. The cable 1 is described in the figure as comprising a current-carrying conductor 2 which comprises transposed both non-insulated and insulated strands. Electromechanically transposed, extruded

insulated strands are also possible. These strands may be stranded/transposed in a plurality of layers. Around the conductor there is an inner semiconducting layer 3 which, in turn, is surrounded by a homogenous layer of a solid insulation material. The insulation 4 is entirely without insulation material of liquid or gaseous type. This layer 4 is surrounded by an outer semiconducting layer 5. The cable used as a winding in the preferred embodiment may be provided with metal shield and external sheath but must not be so. To avoid induced currents and losses associated therewith in the outer semiconducting layer 5, this is cut off, preferably in the coil end, that is, in the transitions from the sheet stack to the end windings. The cut-off is carried out such that the outer semiconducting layer 5 will be divided into several parts distributed along the cable and being electrically entirely or partly separated from each other. Each cut-off part is then connected to ground, whereby the outer semiconducting layer 5 will be maintained at, or near, ground potential in the whole cable length. This means that, around the solid insulated winding at the coil ends, the contactable surfaces, and the surfaces which are dirty after some time of use, only have negligible potentials to ground, and they also cause negligible electric fields.

To optimize a rotating electric machine, the design of the magnetic circuit as regards the slots and the teeth, respectively, is of decisive importance. As mentioned above, the slots should connect as closely as possible to the casing of the coil sides. It is also desirable that the teeth at each radial level are as wide as possible. This is important to minimize the losses, the magnetization requirement, etc., of the machine.

With access to a conductor for the winding such as for example, the cable described above, there are great possibilities of being able to optimize the magnetic core from several points of view. In the following, a magnetic circuit in the stator of the rotating

electric machine is referred to. Figure 2 shows an embodiment of an axial end view of a sector/pole pitch 6 of a machine according to the invention. The rotor with the rotor pole is designated 7. In conventional manner, the stator is composed of a laminated core of electric sheets successively composed of sector-shaped sheets. From a back portion 8 of the core, located at the radially outermost end, a number of teeth 9 extend radially inwards towards the rotor. Between the teeth there are a corresponding number of slots 10. The use of cables 11 according to the above among other things permits the depth of the slots for high-voltage machines to be made larger than what is possible according to the state of the art. The slots have a cross section tapering towards the rotor since the need of cable insulation becomes lower for each winding layer towards the air gap. As is clear from the figure, the slot substantially consists of a circular cross section 12 around each layer of the winding with narrower waist portions 13 between the layers. With some justification, such a slot cross section may be referred to as a "cycle chain slot". Since it will be required, in such a high voltage machine, a relatively large number of layers and the availability of relevant cable dimensions as far as insulation and outer semiconductor are concerned is restricted, it may in practice be difficult to achieve a desirable continuos tapering of the cable insulation and stator slot respectively. In the embodiment shown in Figure 2, cables with three different dimensions of the cable insulation are used, arranged in three correspondingly dimensioned sections 14, 15 and 16, that is, in practice a modified cycle chain slot will be obtained. The figure also shows that the stator tooth can be shaped with a practically constant radial width along the depth of the whole slot.

In an alternative embodiment, the cable which is used as a winding may be a conventional power cable as the one described above. The grounding of the outer semiconducting layer then takes place by stripping the metal shield and the sheath of

the cable at suitable locations.

The scope of the invention accommodates a large number of alternative embodiments, depending on the available cable dimensions as far as insulation and the outer semiconductor layer etc. are concerned. Also embodiments with so-called cycle chain slots can be modified in excess of what has been described here.

As mentioned above, the magnetic circuit may be located in the stator and/or the rotor of the rotating electric machine. However, the design of the magnetic circuit will largely correspond to the above description independently of whether the magnetic circuit is located in the stator and/or the rotor.

As winding, a winding is preferably used which may be described as a multilayer, concentric cable winding. Such a winding means that the number of crossings at the coil ends has been minimized by placing all the coils within the same group radially outside one another. This also permits a simpler method for the manufacture and the threading of the stator winding in the different slots. Since the cable used according to the invention is relatively easily flexible, the winding may be obtained by a comparatively simple threading operation, in which the flexible cable is threaded into the openings 12 present in the slots 10.

The prior solution illustrated in fig 3 comprises a conventional generator 20: this generator feeds, via a circuit breaker 23, a generator transformer or a so-called step-up-transformer. The latter occurs since the conventional generator 20 generates voltage at a relatively low level. The transformer 21 is required to reduce transmission losses, i.e. to increase the voltage to a required extent. The high voltage switch gear is denoted 22. Between the generator and the transformer as well as between the transformer and the switch gear breakers 23 and 24 respec-

tively are arranged. A disconnector is denoted 25. Conventional current and voltage transformers 26 and 27 respectively serving for measuring purposes occur in a conventional manner. The generator 20 is co-ordinated with an excitation transformer 28 and a control unit 29 for excitation. An auxiliary power transformer is denoted 30. This is connected to an auxiliary power switch gear 31.

For the rest, conventional surge diverters serving for overvoltage protection occur. Ground means are denoted 33.

Fig 4 illustrates a switch gear station according to the invention. A high voltage generator 34 provided with one or more windings in accordance with the present invention is at such a high voltage that it may be connected directly to the distribution or transmission network in question via the high voltage switch gear 35. Thus, this means that the step-up-transformer according to the embodiment in fig 3 is not required. A drastic simplification of the switch gear station is the result. Certain additional differences occur. The auxiliary power transformer occurring in the embodiment according to fig 3 is replaced by an auxiliary power winding on the generator 34. For the rest, the noticeable difference is that a particular protection device 36 has been added in the line between the generator and the high voltage switch gear 35. This protection device is intended to operate as an overcurrent limiter. More specifically, this overcurrent limitation function occurs by the device forming a low impedance current path to ground in case of an error having been detected. Since the transformer 21 occurring in the embodiment according to fig 3 have been eliminated in the embodiment according to fig 4, a possible occurring fault, for instance in the insulation system of the generator 34, could cause the full power of the network to load the generator during at least some time before the occurring circuit breakers have time to break. The overcurrent diverting device 36 is intended to function substantially more

rapidly so as to divert, in this way, the overcurrent and avoid the same fully influencing the generator 34. Besides, it is preferred that a current limiting reactor is provided in the line between the generator 34 and the high voltage switch gear 35, said reactor having the property that it will restrict overcurrents in case of faults causing such overcurrents. According to a preferred embodiment, the current limiting reactor is placed in the line 37 between the generator 34 and the high voltage switch gear 35 so that the current limiting reactor becomes located between the connection of the overcurrent diverting device to the line 37 and the generator 34, i.e. such that the reactor will operate current limiting for current tending to flow from the network in a direction towards the generator in case of some fault therein.

Fig 5 illustrates in perspective view a conventional switch gear station comprising two generators 38 each feeding, via high current bars 39 and a high current switch gear module 40, feed a step-up-transformer 41, said transformer in its turn being connected to the high voltage switch gear 42. Further auxiliary equipment such as auxiliary power transformers etc. will be added. Besides, it is pointed out that the transformers 41, which are of a conventional oil-filled embodiment, require fire separations in the form of walls etc. and safety measures in the form of oil-collecting plants. As can be seen, the station in its entirety is extremely complexe and costly. It is to be mentioned that the oil insulated transformers 41 are placed outside the building 43 containing the generators due to the substantial fire hazard associated to oil-filled transformers.

Fig 6 illustrates use of the invention, i.e. direct connection of high voltage generators 44 directly to power networks without intermediate step-up-transformers. As has been explained before, the key to this possibility is the design of the windings of the generators. It is indicated in fig 6 that cables 45 running from the generators 44 extend to the high voltage switch gear 46. The

very simple connection between the generators and the network by means of a high voltage cable drastically reduces the cost as compared to the more expensive equipment required in the embodiment according to fig 3. Furthermore, transformers etc. may be eliminated. The design according to fig 6 is substantially more friendly to the environment since transformer oil may be entirely avoided. Also the fire hazard is reduced markedly.

Fig 7 illustrates a conventional embodiment for Static VAR Compensation (SVC) and a switch gear. An SVC-station consists normally of switching apparatus in the high voltage switch gear 47, a transformer 48 transforming the voltage down to a level which the thyristors 49, 50 may handle, reactors, capacitors and double direction thyristor valves. Most transmission applications require an automatic voltage regulator (AVR) as thyristor control. A disadvantage with this plant is that many apparatuses are required and that they occupy a large space.

Fig 8 illustrates a station according to the invention having a rotating synchronous compensator and a high voltage switch gear 52. No transformer is required between the synchronous compensator and the high voltage switch gear since the synchronous compensator 51 is designed so that it can manage the transmission voltage in question, which is a consequence of the fact that the winding of the synchronous compensator has been achieved by means of a cable according to the invention.

As is apparent from fig 8, the embodiment becomes much more simple than the one in fig 7 and it also requires less space.

Fig 9 illustrates a conventional switch gear station provided with a static converter in "back-to-back" design having a DC-link. As can be seen, an important disadvantage with this type of station is that the required surface becomes large, mainly as a conse-

quence of the amount of filters. The transformers are complicated and particularly adapted to these plants.

Fig 10 illustrates a diagram over a switch gear station comprising rotating converters 53. Each of these converters consist of a motor/generator provided with a winding in accordance with the description given hereinabove. The embodiment according to fig 10 is particularly suitable when communication is to be established between two different networks having different parameters in some regard. For instance, the network 54 may be at a different voltage level, a different phase position, a different frequency or have another number of phases than the second AC network 55. The illustrated connection of the networks by means of motors/generators where one of the units 53 will drive the other solves a communication problem without causing any disturbances between the networks. As before, high voltage switch gears 56 and various breakers etc. occur. The protection device 36 described more closely with the aid of the embodiment in fig 4 occurs also here and more specifically in a doubled set under the designation 57 on either sides of the pair of motors/generators. Thus, the protection devices 57 will protect the pair of motor/generator from both networks 54, 55. For the rest, constituents already explained by means of previous drawing figures occur also here.

It appears from the above description that the switch gear station according to the invention involves distinct advantages over prior art in a number of different embodiments of rotating electric machines comprising magnetic circuits. The basic advantages with the invention have already been dealt with hereinabove. As an additional point it should also be emphasised that it is of considerable importance that the design according to the invention of the winding of the machine will result in a better environment close to the switch gear station as a consequence of lower mag-

netical and electrical field around the machine and in particular at its cable connection.

POSSIBLE MODIFICATIONS

It is evident that the invention is not only limited to the embodiments illustrated above. Thus, men skilled within this art will realise that a number of detailed modifications are possible when the basic concept of the invention has been presented without deviating from the concept as it is defined in the enclosed claims. As an example, it is pointed out that the invention is not only restricted to the specific material selections exemplified above. Functionally equal materials may, accordingly, be used instead. As far as the manufacturing of the insulation system according to the invention is concerned, it is pointed out that also other techniques than extrusion and spraying are possible as long as intimacy between the various layers is achieved. Furthermore, it is pointed out that additional equipotential layers could be arranged. For example, one or more equipotential layers of semiconducting material could be placed in the insulation between those layers designated as “inner” and “outer” hereinabove.

Claims

1. Switch gear station comprising at least one switch gear (35, 46, 52) and at least one rotating electric machine for high voltage, said machine comprising at least one winding (1) including at least one electric conductor (2), *characterized* in that the winding (1) comprises an insulation system including an insulation (4) formed by a solid insulation material and interiorly thereof an inner layer (3) having an electrical conductivity which is lower than the conductivity of the electric conductor but sufficient to cause the inner layer (43) to operate for equalisation of potential and, accordingly, equalisation as concerns the electrical field exteriorly of the inner layer.

2. A station according to claim 1, *characterized* in that the insulation system exteriorly of the insulation comprises an outer layer (5) which has an electrical conductivity which is higher than that of the insulation to make the outer layer capable, by connection to earth or otherwise a relatively low potential, of operating to equalise potential, and of substantially enclosing the electric field, arising as a consequence of said electrical conductor (2), inwardly of the outer layer (5).

3. A station according to claim 1 or 2, *characterized* in that said at least one conductor (2) forms at least one induction turn.

4. A station according to any preceding claim, *characterized* in that the inner and/or outer layer (3, 5) comprises a semiconducting material.

5. A station according to any preceding claim, *characterized* in that the inner layer (3) and/or the outer layer (5) has a resistivity in the range 10^{-6} Ωcm-100 kΩcm, suitably 10^{-3}-1000 Ω cm, preferably 1-500 Ωcm, and in particular 10-200 Ωcm.

6. A station according to any preceding claim, *characterized* in that the inner layer (3) and/or the outer layer (5) has a resistance which per length meter of the conductor/insulation system is in the range 50 $\mu\Omega$ - 5 $M\Omega$.

7. A station according to any preceding claim, *characterized* in that the solid insulation (4), the inner layer (3) and/or the outer layer (5) are formed by polymeric materials.

8. A station according to any preceding claim, *characterized* in that the inner layer (3) and/or the outer layer (5) and the solid insulation (4) are rigidly connected to each other over substantially the entire interface to ensure adherence between the respective layers and the solid insulation on temperature changes and flexing of the conductor and its insulation system.

9. A station according to any preceding claim, *characterized* in that the inner layer (3), the outer layer (5) and the solid insulation (4) are formed by materials having substantially equal thermal coefficients of expansion.

10. A station according to any preceding claim, *characterized* in that the inner layer (3) and the outer layer (5) are achieved by extruding simultaneously with extruding of the rigid insulation (4).

11. A station according to any preceding claim, *characterized* in that the conductor (2) and its insulation system constitutes a winding formed by means of a flexible cable (1).

12. A station according to any of claims 2-11, *characterized* in that the inner layer (3) is in electric contact with the at least one electric conductor (2).

13. A station according to claim 12, *characterized* in that said at least one electric conductor (2) comprises a number of strands and at least one strand of the electric conductor (2) is at least in part uninsulated and arranged in electric contact with the internal layer (3).

14. A station according to any preceding claim, *characterized* in that the inner and outer layers (3, 5) and the insulation (4) are of materials having such an elasticity that the layers maintain their adherence to the rigid insulation despite the temperature variations occurring under operation.

15. A station according to claim 14, *characterized* in that the materials in the layers and the solid insulation have an E modulus which is less than 500 MPA, preferably less than 200 MPA.

16. A station according to any of claims 14 and 15, *characterized* in that the adherence between the layers and the insulation is at least in the same order as in the weakest of the materials.

17. A station according to any preceding claim, *characterized* in that the conductor (2) and its insulation system are designed for high voltage, suitably in excess of 10 kV, in particular in excess of 36 kV and preferably more than 72,5 kV.

18. A station according to any preceding claim, *characterized* in that the outer layer (5) is divided into a number of parts, which are connected to earth or otherwise a low potential on their own.

19. A station according to claim 1, *characterized* in that said at least one winding is arranged in the stator and/or rotor of the machine.

20. A station according to any of claims 1 and 19, *characterized* in that the magnetic field generator circuit comprises one or more magnetic cores (8) having slots (10) for the winding (1).

21. A station according to claims 19-20, *characterized* in that with connection of the outer layer (5) to ground potential, the electrical field of the machine outside the outer layer will be near zero both in the slot (10) and in the coil-end-region.

22. A station according to any of claims 19-21, *characterized* in that the slots (10) are formed as a number of actually extending cylindrical openings (12) arranged radially outwardly of each other and separated by a narrower waist portion between the cylindrical openings.

23. A station according to claim 22, *characterized* in that the cross section of the openings of the slots (10) decreases, counted from a back portion (8) of the magnetic core.

24. A station according to claim 23, *characterized* in that the cross section of the slots (10) decreases continuously or discontinuously.

25. A station according to any of claims 19-24, *characterized* in that the machine is constituted of a generator, motor or synchronous compensator.

26. A station according to claim 25, *characterized* in that the generator is a hydrogenerator or turbogenerator.

27. A station according to any of claims 1-26, *characterized* in that the machine is directly connected to a power network for

high voltage, suitably 36 kV and more, without intermediate transformer.

28. A station according to claim 27, *characterized* in that the rotating electric machine is connected to the switch gear via one or more flexible cables forming continuations of the winding in the machine.

29. A station according to claim 25 and 27, *characterized* in that the machine is connected to a distribution or transmission network via the switch gear.

30. A station according to any preceding claim, *characterized* in that the rotating electric machine is formed by a rotating synchronous converter or an asynchronous converter.

31. A station according to any preceding claim, *characterized* in that an overcurrent diverting device (36) is connected to a line between the rotating electric machine and the switch gear to divert, in the case of a fault, possible overcurrents to earth or otherwise a lower potential.

32. A station according to any preceding claim, *characterized* in that a current limiting reactor is connected to the line between the rotating electric machine and the switch gear in order to limit overcurrents caused by a fault.

INTERNATIONAL SEARCH REPORT

International application No.
PCT/SE 98/02149

A. CLASSIFICATION OF SUBJECT MATTER

IPC6: H02K 3/00, H02B 1/00
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC6: H02B, H02K

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

WPI

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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Y	US 4360748 A (H-G. RASCHBINDER ET AL), 23 November 1982 (23.11.82), column 3, line 18 - column 4, line 33, figures 1-3 --	1-32
Y	US 5036165 A (R.K. ELTON ET AL), 30 July 1991 (30.07.91), figure 1, abstract --	1-32

[X] Further documents are listed in the continuation of Box C. [X] See patent family annex.

* Special categories of cited documents:
- "A" document defining the general state of the art which is not considered to be of particular relevance
- "E" erlier document but published on or after the international filing date
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- "O" document referring to an oral disclosure, use, exhibition or other means
- "P" document published prior to the international filing date but later than the priority date claimed
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- "X" document of particular relevance: the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
- "Y" document of particular relevance: the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
- "&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
1 March 1999	22 -03- 1999

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/SE 98/02149

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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Information on patent family members

International application No.
PCT/SE 98/02149

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